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SPITZER/IRS[1] OBSERVATIONS OF THE REDSHIFT 3.91 QUASAR APM 08279+5255[2]

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ABSTRACT

The Infrared Spectrograph (IRS) onboard the Spitzer Space Telescope (SST) has been used to obtain low and moderate resolution spectra of the dust and gas-rich quasar APM 08279+5255 (z=3.91). Broad Paschen α and β recombination lines of hydrogen were detected at wavelengths of 9.235 and 6.315μm, as well as a strong, red continuum that is a smooth power law over the observed (rest frame) wavelength range 5.3-35μm (1.08 - 7.1μm). The observed Pα/Pβ line flux ratio of 1.05$\pm$0.2 is far from the case B value of $\sim$2 and simple models of high density, high optical depth ionized gas regions ($\sim$1.8). This deviation is opposite in sense to the expected effect of reddening.

No evidence is found in the spectrum for either the 3.3μm or 6.2μm emission features usually attributed to aromatic hydrocarbons in gas rich galaxies in the local Universe. This is consistent with the high luminosity AGN nature of APM 08279+5255.

Subject headings: quasars, spectroscopy, quasars individual: APM 08278+5255

1. INTRODUCTION

The quasar APM 08279+5255 was originally discovered in a survey for high galactic latitude carbon stars(Irwin et al. 1998). At a redshift z=3.91 (Downs et al. 1999), its brightness makes APM 08279+5255 apparently the most luminous object known in the universe. As originally suggested by Irwin et al. and subsequently confirmed by Ibata, et al. (1999) and Egami et al. (2000) APM 08279+5255 is strongly gravitationally lensed, with a magnification of $\sim$100. The lensing reduces its intrinsic bolometric luminosity to a more modest but still large $\sim 5\times 10^{13} L_\odot$.

Although APM 08279+5255 does not have a strong infrared excess for quasars (see, e.g. Wilkes, 2001), it is a bright source in the IRAS point source catalog (JISWG, 1989, Irwin et al. 1998). It has been detected in the millimeter and submillimeter continuum (Lewis et al. 1998) and in multiple CO emission lines (e.g. Downs, et al. 1999, Papadopoulos et al. 2001), demonstrating that the lensed quasar system is dust and gas-rich. The mass of molecular gas is $1-10\times 10^9 M_\odot$, depending on the lensing magnification (Downs et al., Lewis, et al. 2002). The presence of large quantities of gas and dust in such a high redshift system makes it a prime candidate to search for complex molecules at high redshift. The spectral energy distribution of APM 08279+5255 at far infrared and submillimeter wavelengths is well-fitted with a black body of temperature $\sim$220K (Lewis et al.) and has a continuum level well above 70 mJy for observed wavelengths $\lambda > 12\mu$m. The spectral energy distribution of APM 08279+5255 is normal for radio quiet quasars. Its unusual brightness makes it ideal for study by the Spitzer Space Telescope (SST) as an example of a high redshift quasar, and makes it of great interest for probing the nature of quasars at very large lookback times.

APM 08279+5255 was therefore selected as an early release observation target for the Infrared Spectrometer (IRS) on the SST. The following sections describe the observations and data reduction, the IRS data, and their implications.

2. OBSERVATIONS AND DATA REDUCTION

APM08279+5255 was observed by the Spitzer/IRS on 26 October 2003 and 23 November 2003. In order to ensure proper target placement on the IRS slits, the spectroscopic observations were preceded by target acquisition in the IRS peak-up imager (Houck et al. this issue, hereafter Paper I). Table 1 presents the log of the Spitzer observations. For the low resolution spectra, observations were obtained at two positions along the IRS slit to enable sky subtraction. High resolution spectra were obtained of both the target and a blank nearby patch of sky that was used for sky subtraction. Because of the substantially higher signal-to-noise ratios of the 23 November observations, where there was overlap between observations on the two dates, we include only those data from 23 November in the subsequent discussion.

The data were processed through the IRS data pipelines at the Spitzer Science Center (Paper I) to produce calibrated data frames. The data were converted from slopes to integrated signals, linearized, dark subtracted and cosmic rays were removed. Flat field corrections were applied, as were wavelength calibrations. Multiple frames covering the same wavelength range were

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[2] based on observations obtained with the Spitzer Space Telescope, which is operated by JPL, California Institute of Technology for the National Aeronatics and Space Administration

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TABLE 1
Observation Log

λ_{range}[μm]	$\lambda/\Delta\lambda$	t_{int}[sec]	Observation Date
10 – 19.5	600	240	26 Oct[a]
19 – 37	600	240	26 Oct
7.5 – 14	80	56	26 Oct
19 – 37	600	480	23 Nov[b]
5.3 – 8.5	80	56	23 Nov
7.5 – 14	80	56	23 Nov
14 – 21.8	80	84	23 Nov
20.6 – 40	80	84	23 Nov

[a]600 second sky dark obtained on 23 Nov
[b]300 second sky dark obtained on 23 Nov

combined, and one-dimensional sky-subtracted spectra of the target quasar were extracted from the combined data.

The photometric calibration of the spectrum was based on Spitzer observations of standard stars (Paper I), while the wavelength calibration was based on observations of emission line stars and planetary nebulae (Paper I). At this time we estimate that the overall uncertainty in the wavelength calibration is $\pm0.04\mu$m at 20μm for the low resolution spectra, and $\pm0.006\mu$m at 20μm for the high resolution spectra.

3. RESULTS

The low resolution spectrum, plotted as flux density vs. observed(rest) wavelength, is plotted from 5–38 (1.1–7.7) μm in Figure 1. No features were seen in the high resolution spectrum that were not present in the low resolution spectrum. Because of the present uncertainties in the IRS calibration, the long-low spectrum was scaled by factor of 0.78, to match with the short-low spectrum and to bring the flux density into agreement with the flux density observed at 18μm by Egami et al. (2000). The overall level agrees well with the flux density reported at 12.5 μm by Egami et al. With this adjustment the spectrum of APM08279+525 is nearly featureless, being dominated by a remarkably smooth continuum. Fitting the continuum by eye as a power law, the slope is $f_\nu \sim \nu^{-1.21}$ for $\lambda > 15\mu$m ($>2.85\mu$m in the rest frame). This continuum fits the IRAS measured flux densities at 60 and 100 μm remarkably well. For wavelengths $\lambda < 15\mu$m ($<2.85\mu$m in the rest frame), the slope steepens considerably, to $f_\nu \sim \nu^{-2.26}$. There are no broad emission features present in the spectrum.

Since the background quasar is gas/dust rich, it might have been expected that the emission bands of dust or organic molecules (PAH) would be present, but none has been detected in the spectrum. Upper limits to the fluxes of the PAH bands at 3.3 and 6.2μm are given in Table 2. The rise in the spectrum at the longest wavelengths ($>35\mu$m) might indicate the presence of a weak PAH feature at a rest wavelength of 7.7μm, but the signal-to-noise ratio in this is low, and flat fielding and calibration issues at the long wavelength end of the spectrum make the reality of this feature questionable at best. We therefore do not consider it real.

The only spectral features detected are emission lines at wavelengths of 6.315μm and 9.235μm. These features correspond to redshifted hydrogen recombination lines Paschen β and Paschen α, respectively, in the spectrum of the lensed quasar. The lines are well resolved even in the low resolution spectra presented here ($R=\Delta\lambda/\lambda \sim 80$, Paper I). The central wavelengths, widths, and fluxes of the lines are presented in Table 2, as are the upper limits of the line flux and equivalent width for Brackett α.

4. DISCUSSION

The most notable features of the infrared spectrum of APM08279+5255 are the smooth, steep continuum, and the Paschen recombination lines. The continuum that rises smoothly to the longest observed wavelengths is consistent with a model of dust in an accretion disk heated by an underlying central source. Such an interpretation of the infrared continuum of quasars has been presented by Phinney (1989) and Sanders et al.(1989). These models have been extended to toroidal disks by Pier and Krolik (1992, 1993) and clumpy media by Elitzur, Nenkova and Ivezic (2003).

The presence of substantial emission at rest wavelengths $\lambda_{rest} > 2\mu$m argues for temperatures approaching the sublimation temperature of refractory dust. The change in the continuum slope at a rest wavelength of 3μm is consistent with a decrease in dust abundance for $T_{dust} > 1000$K, consistent with the sublimation temperature of silicate grains (Salpeter, 1974). The overall continuum of APM 08279+5255, as mentioned above, is rather typical for radio quiet quasars, without a pronounced infrared peak. This suggests, in the "unified scheme" that we are viewing the AGN accretion disk close to face on (c.f. Elitzur et al. 2003).

The non-detection of PAH features at 3.3μm and 6.2μm in the spectrum of APM08279+5255 is consistent with the trend found in nearby AGNs for Seyfert 1 systems and quasars to have weak or non-existent emission features associated with PAHs (Tran et al. 2001). It should be noted that evidence for PAH bands has been found in some "infrared-loud" quasar spectra (e.g. Mk 1014 - see Armus et al. 2004), so this is not a universal phenomenon. Organic molecules such as PAHs appear to be destroyed in the harsh environments of quasars. It is likely that this process is at work in APM 08279+5255, so no conclusions can be reached based on these observations about the abundances of such molecules in the host galaxy of this quasar.

Another significant caveat regarding the interpretation of the non-detection of PAH bands is the gravitational lensing, with the potential for substantial differential magnification of different regions within the source plane. This effect is clearly illustrated in the three image model of Egami et al.(2000). For example a region of hot dust emission located close to the caustics would be much more magnified than a more extended source such as would be expected of a PAH emitting region. This would have the effect of substantially reducing the equivalent width of any PAH bands in the *observed* spectrum.

The measured redshifts of the Pα and Pβ lines (Table 2) are consistent with the redshift determined from the CO lines (Downs et al. 1999), and greater than the redshift determined from the rest UV spectral features (Irwin et al. 1998). The line fluxes for the Pα and Pβ lines (Table 2) lead to an observed line ratio of

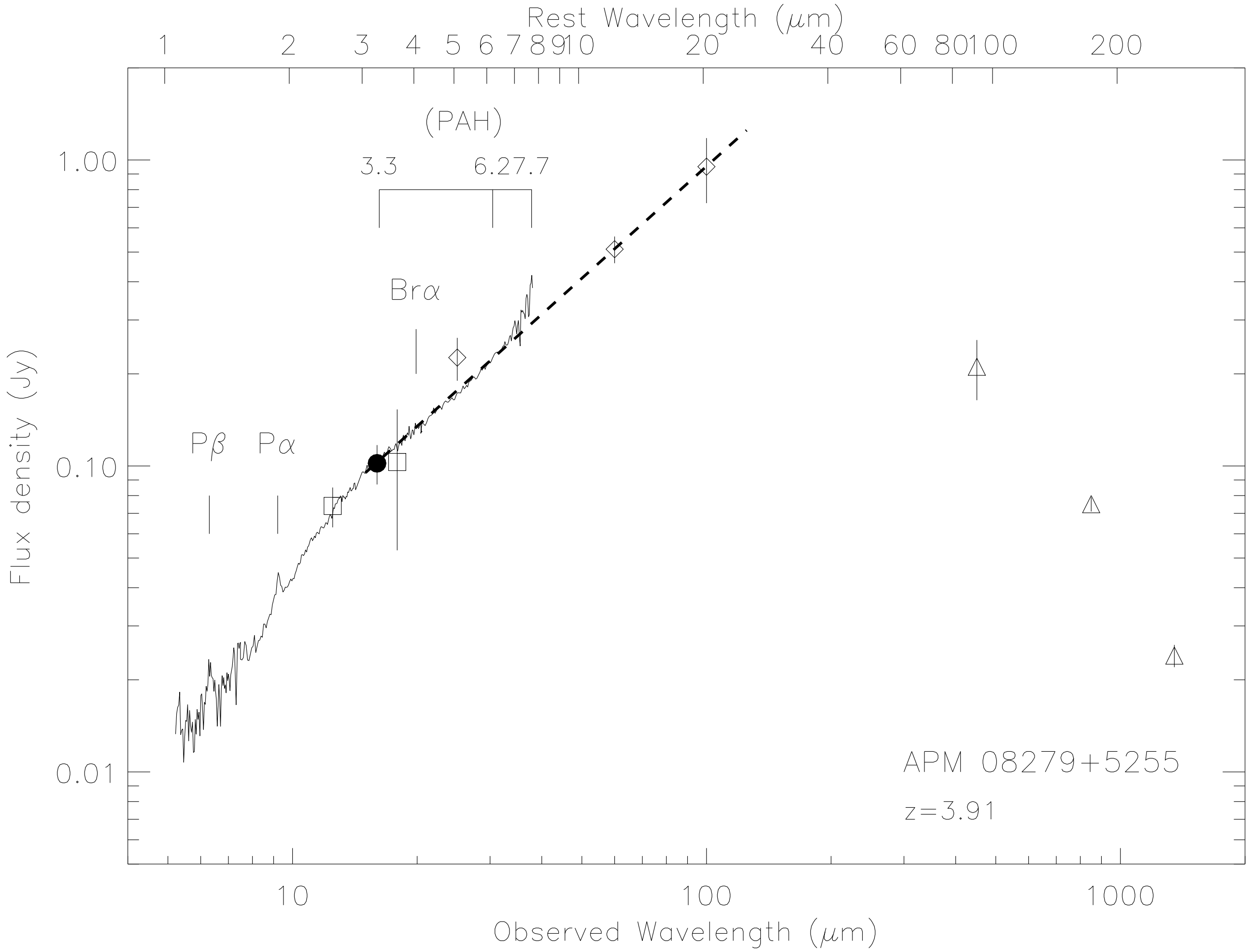

Fig. 1.— The mid-infrared spectra of APM08279+5255, plotted as flux density vs. wavelength (observed - bottom, restframe - top). In addition to the IRS spectrum, the flux density as measured in the IRS peak-up camera at 16μm is plotted as the filled circle. The IRAS flux densities at 25, 60 and 100 μm (JISWG, 1989) are plotted as open diamonds, the flux densities measured by Egami et al. (2000) at 12.5μm and 18 μm are plotted as open squares, and the submillimeter observations of Lewis et al. (1998) are plotted as open triangles . A power-law fit to the continuum for $\lambda_{observed}$ >15μm is shown as a dashed line. Wavelengths of hydrogen recombination lines and expected PAH features are indicated in the plot.

TABLE 2
Observed Line Properties in APM08279+5255

Line	Observed Wavelength [μm]	z	Equivalent Width [observed μm]	Equivalent Width [rest μm]	Δv FWHM [km s^{-1}]	Observed Flux [W cm^{-2}]
Paschen α	9.235±0.011	3.925±0.006	0.059	0.012	8770	$8.5\pm1.1\times10^{-21}$
Paschen β	6.315±0.013	3.914±0.011	0.061	0.012	9500	$8.1\pm1.6\times10^{-21}$
Brackett α	19.89 [a]	–	<0.016 [b]	0.003 [b]	–	$<1.6\times10^{-21}$ [b]
3.3μm	16.203 [a]	–	<0.01 [b]	0.002 [b]	–	$<1.0\times10^{-21}$ [b]
6.2μm	30.442 [a]	–	<0.03 [b]	0.006 [b]	–	$<2.3\times10^{-21}$ [b]

[a] assumed redshift 3.91
[b] 3σ upper limit

Pα/Pβ=1.05±0.2. This ratio is substantially less than predicted value of 2 from Case B recombination (Hummer and Storey 1987) and models that allow for high density and large optical depths in the Paschen lines (Drake and Ulrich, 1980, Lynch et al. 2000), which predict values for this ratio of 1.8-2. Reddening would drive the line ratio to greater values, and so cannot be invoked to explain the observations. The upper limit on the flux in the Br α line, reported in Table 2, leads to a limit on the ratio of Brα/Pα < 0.19. This value is close to the case B

value of 0.24 and the high density, optically thick models of Drake and Ulrich and Lynch et al. of $\sim$0.2. The limit on the ratio $\mathrm{Br}\alpha/\mathrm{P}\beta < 0.2$ is significantly smaller than the case B ratio of 0.5, but is close to the Drake and Ulrich and Lynch et al. models of $\sim$0.2 for this ratio. Clearly, more detailed physical models of the broad line regions in the Paschen lines are needed to account for the observed line ratios.

The ratio of the observed Paschen lines to Lyman α and / or Hα would be most interesting to establish the physical conditions in the broad line region and the reddening to this region. Unfortunately the line profile of Lyman α is strongly affected by the intervening column of neutral hydrogen (Irwin, et al. 1998), making straightforward comparisons fruitless. In addition, Hα falls longward of the wavelengths reachable with sensitive near infrared spectrometers. Hβ is potentially reachable from groundbased telescopes, but no such observations have been published to date.

The line widths from the fits to the Paschen lines (9000 $\mathrm{km\,s^{-1}}$) are consistent with those found for broad lines in quasars. Again, the observed broad UV lines in APM08279+5255 are heavily affected by intervening absorption (e.g. Irwin, et al. 1998, Hines, Schmidt and Smith, 1999), so no meaningful comparison of the Paschen and UV linewidths can be made.

5. SUMMARY

The observed mid-infrared spectrum of the high redshift lensed quasar APM08279+5255 has shown recombination lines of Pα and Pβ, and a remarkably smooth overall continuum that rises sharply into the far infrared. The continuum shows a steepening in the continnum for wavelengths $\lambda < 15\mu$m (2.85μm in the rest frame of the lensed quasar). This is suggestive of the temperature of sublimation of silicate grains in a quasar accretion disk. No features characteristic of organic molecules, such as aromatic features, are seen in the spectrum. The ratio Pα/Pβ is far from that predicted by models of the high density, high optical depth gas believed to be in the quarar broad line region, in the sense opposite to that expected from dust reddening.

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